

In addition to the 16 elements (C,H,O; 6 macronutrients—N, P, K, S, Ca, Mg; 7 micronutrients—Fe, Mn, Cu, Zn, B, Mo, Cl) that are considered essential for plant growth, according to the criteria proposed by Arnon and Stout (1939), a number of other elements have been reported to be essential, or at least beneficial, by way of increased growth or improved resistance to diseases or pests for some species. These elements, which include Na, Si, Co, Ni, La, Ce, V, and even Al, are currently considered as beneficial plant nutrients. Recognition of the role of some of these elements resulted from the improvement in research methodology and plant chemical analytical techniques, since some of these elements may be present in concentrations less than a few parts per billion ($\mu\text{g kg}^{-1}$). More than half the elements in the Periodic Table are known to occur in plant tissues (Asher, 1991). Thus there are a fairly large number of elements about which little is known concerning their roles in the tissue of one or more species; is it merely a coincidence or do they have a specific role?

It may be mentioned that there has been considerably more research on nutrient essentiality in animals than in plants and plant products. Between 1957 and 1973 the essentiality of seven new trace elements (F, Si, V, Cr, Ni, Se, Sn) for warm-blooded animals was established (Schwarz, 1974), and about 19 others are being considered. It is important that plants absorb these elements in adequate quantities, whether they are required for plant growth or not (Asher, 1991). The case for Co in herbage is an example. A brief discussion on a few elements considered beneficial for plants follows.

17.1. SODIUM

Sodium makes up about 2.6% of the earth's crust and is the sixth most abundant element. It is also present as a major component of seawater. Sodium has generally received the attention of the soil scientist because it is a problem element in sodic soils. However, the following findings need consideration.

1. Sodium is required for the conversion of pyruvate to phosphoenol pyruvate in the mesophyll in C_4 plants (Johnson et al., 1988). External Na concentrations $\leq 100 \mu\text{M L}^{-1}$ have been shown to be needed for maximum growth of C_4 plants (Brownell, 1968).
2. Sodium is required for assimilation of NO_3^- and conversion to NO_2^- and other intermediates in blue-green alga *Anabaena cylindrica* (Brownell, 1968).
3. Sodium is reported to increase growth of halophytes even when adequate K is present; this has been attributed to increased turgor (Flowers et al., 1977).
4. Some glycophytes, notably sugarbeet (*Beta vulgaris*, L.), respond positively to Na even in the presence of adequate K; Na is also reported to increase sugar concentration (El-Seikh and Ubrich, 1970).
5. Sodium can partly substitute for K in several species, and it is possible that it may be involved in different mechanisms in different species. Two generally reported mechanisms are (a) improved stomatal function (Raghvendra et al., 1976) and (b) osmotic and electrical balance of cells (Asher, 1991).
6. Sodium can overcome the impairment of carbohydrate transport associated with Ca deficiency (Joham and Johanson, 1973).
7. Sodium deficiency of grazing cattle has been reported from several parts of the world (Playne, 1970), and Na concentration in herbage is an important quality factor in relation to animal nutrition.

Thus for halophytes, glycophytes, cultures of blue-green algae, and herbage plants, Na nutrition seems to be important.

17.2. SILICON

Silicon is the second most abundant element in the lithosphere, accounting for about 26% by weight. Silicon is regarded as an essential trace element for the normal growth and development of higher animals since it is involved in the formation of bones and cartilages. Essentiality of Si for the growth of several species of diatom was reported as early as 1933 (King and Davidson, 1933). Regarding the crop plants, the following need to be considered.

1. Silicon has been found necessary for the normal growth of rice (Okawa, 1936, 1937), sugarcane (Fox et al., 1967), barley (Okawa, 1937), and beet (Raleigh, 1939).
2. In rice and sugarcane, application of silicate materials has entered commercial practice; yield increase in sugarcane due to 4.5 t ha^{-1} CaSiO_3 application in a study was about 10 t ha^{-1} of millable cane

(Fox et al., 1967). Silicate application resulted in a 3 to 13% increase in rice grain yield in Japan, Korea, and Taiwan.

3. Some of the yield increase in rice could be due to increased resistance to fungal diseases such as blast (Ishizuka and Hayakawa, 1951), to insect attack, and to Mn toxicity (Okuda and Takahashi, 1962).
4. Plants differ widely in respect of Si absorption from soil. The members of Cyperaceae (e.g. *Equisetum arvens*) and rice can accumulate >4% Si in the dry matter of their tops compared with <0.5% in dicots; dryland Graminaceae form an intermediate group (Asher, 1991).
5. Reduced pollen viability in the absence of Si has been reported in tomatoes (*Lycopersicon esculentum*, Mill), cucumbers (*Cucumis sativus* L.), soybeans [*Glycine max* (L.) Merr.], and strawberries (*Fragaria ananassa* Duchesne) (Miyake and Takahashi, 1986).
6. The addition of Si is reported to increase P availability in soils (Suehisa et al., 1963), and this can result in improved plant growth and increased crop yield.
7. The addition of Si may decrease the solubility of Al and heavy metals that may otherwise be present in toxic levels.

The above observations indicate that Si may be essential for the growth of plants of some species, but failure to complete their life cycle has not yet been demonstrated.

17.3. COBALT

Cobalt is involved in N₂-fixation and is therefore essential for legumes (Ahmed and Evans, 1960). Field responses of subterranean clover (*Trifolium subterraneum* L.) in Australia have been reported (Ozanne et al., 1963). Narrow-leaved lupins (*Lupinus angustifolius* L.) are reported to be especially responsive to Co fertilization. Cobalt is also reported to be essential for N₂-fixation in nonlegumes, for example, in *Alnus* and *Azolla*. Essentiality of Co for plants not dependent on N₂-fixation has not been established.

Cobalt is essential for ruminants, where it is involved in the synthesis of vitamin B₁₂ (Underwood, 1984). Inadequate dietary Co leads to wasting disease characterized by anemia and the loss of appetite. In the case of breeding ewes Co deficiency can lead to reduced lamb weights at birth and poor lamb survival (Norton and Hales, 1976).

17.4. NICKEL

Nickel like Al has mostly received the attention of soil scientists and agronomists from the viewpoint of its toxic effects on plant growth; the toxicity

symptoms resemble Fe deficiency symptoms. A characteristic feature of Ni toxicity in cereals and grasses is a variation in the intensity of chlorosis along the length of the leaf, yielding a series of transverse bands (Anderson et al., 1973).

The discovery that the urease from jackbean (*Canavalia ensiformis* [L.] DC) is an Ni metalloenzyme (Dixon et al., 1975) elevated its status of Ni to that of a functional nutrient. (This term was coined to describe an element that plays a role in plant metabolism, whether or not that role is specific or indispensable). The role of Ni in urea metabolism of plants was reviewed by Walker et al. (1985).

Brown et al. (1987) showed that Ni is essential for grain viability in barley. At grain Ni concentrations $<100 \mu\text{g kg}^{-1}$, germination percentage decreased linearly with decreasing Ni concentrations. These findings strengthen the claim of Ni as an essential nutrient for plant growth. Mishra and Kar (1974) cited several instances where the application of Ni had improved growth of plants. The essentiality of Ni as a plant nutrient in soybeans, chickpeas (*Cicer arietinum* L.), and temperate cereals (Brown et al., 1987) has been illustrated, but its essential function in higher plants other than in urease metabolism has yet to be established.

17.5. ALUMINUM

The toxic effects of excess Al in acidic soils have been discussed in Chapter 6. Aluminum, when not present in toxic levels yet in abundant amounts, is reported to reduce the toxic level for uptake of Cu, P (Asher, 1991), and Zn.

Stimulatory effects of Al on plant growth have been observed in Al accumulators such as tea (*Camellia sinensis* [L.] Kuntze) as well as non-Al accumulators.

17.6. VANADIUM, LANTHANUM, AND CERIUM

Vanadium is reported to stimulate growth and nitrogenase synthesis in *Anabaena variabilis* cells in the absence of Mo (Yakunin et al., 1991). While excessive amounts can be toxic to microorganisms, some Va is required for their growth. In a study by Lyalikova and Yurkova (1989) 0.6 g L^{-1} of Va was found to be optimal for the growth of microorganisms.

Large-scale use of a fertilizer called Nongle (“Happy Farmer”), containing La and Ce nitrates, is reported from China (Guo, 1987). An increase in yield of the order of 5 to 15%, as well as product quality improvement, is reported in a number of annuals and perennials. Soils containing less than 5 to 10 mg kg^{-1} sodium acetate–acetic acid buffer (pH 8.0) extractable rare earths are considered responsive to Nongle application (Zhu and Liu, 1985). No evidence of essentiality of La and Ce has been produced.

REFERENCES

- Ahmed, S. and H.J. Evans. 1960. Cobalt: a micronutrient element for the growth of soybean plants under symbiotic conditions. *Soil Sci.* 90:205–210.
- Anderson, A.J., D.R. Meyer, and F.K. Meyer. 1973. Heavy metal toxicities: levels of nickel, cobalt, and chromium in the soil and plants associated with visual symptoms and variation in growth of an oat crop. *Aust. J. Agric. Res.* 24:557–571.
- Arnon, D.I. and P.R. Stout. 1939. The essentiality of certain elements in minute quantity for plants with special reference to copper. *Plant Physiol.* 14:371–375.
- Asher, C.J. 1991. Beneficial elements, functional elements and possible new essential elements, *Micronutrients in Agriculture*, Soil Sci. Soc. Am., Madison, WI, pp. 703–723.
- Brown, P.H., R.M. Welch, and E.E. Cary. 1987. Nickel: a micronutrient essential for higher plants. *Plant Physiol.* 85:801–803.
- Brownell, P.F. 1968. Sodium as an essential micronutrient element for some higher plants. *Plant Soil* 28:161–164.
- Dixon, N.E., C. Gazzola, R.L. Blackley, and B. Zerner. 1975. Jack bean urease (EC 3.5.1.5). A metalloenzyme. A simple biological role for nickel. *J. Am. Chem. Soc.* 97:4131–4133.
- El-Sheikh, A.M. and A. Ulrich. 1970. Interactions of rubidium, sodium, and potassium on the nutrition of sugarbeet plants. *Plant Physiol.* 46:645–649.
- Flowers, T.J., P.F. Troke, and A.R. Yeo. 1977. The mechanism of salt tolerance in halophytes. *Ann. Rev. Plant Physiol.* 28:89–121.
- Fox, R.L., J.A. Silva, O.R. Younge, D.L. Plunknett, and G.D. Sherman. 1967. Soil and plant silicon and silicate response by sugarcane. *Soil Sci. Soc. Am. Proc.* 31:775–779.
- Guo, B. 1987. A new application of rare earths — agriculture, in *Rare Earth Horizons*, Aust. Dept. Industry and Commerce, Canberra, Australia, pp. 237–246.
- Ishizuka, Y. and Y. Hayakawa. 1951. Resistance of rice plant to the Imodhi (rice blast) disease in relation to their silica and magnesia contents. *J. Sci. Soil and Manure, Japan* 21:253–260.
- Joham, H.E. and L. Johanson. 1973. The effects of sodium and calcium on the translocation of ^{14}C -sucrose in excised cotton roots. *Physiol. Plant.* 28:121–126.
- Johnson, M., C.P.L. Graf, and P.F. Brownell. 1988. The effect of sodium nutrition on the pool sizes of intermediates of the C_4 pathway. *Aust. J. Plant Physiol.* 15:749–760.
- King, E.J., and V. Davidson. 1933. The biochemistry of silicic acid. IV. Relation of silica to the growth of phytoplankton. *Biochem. J.* 27:1015–1021.
- Lyalikova, N.N., and N.A. Yurkova. 1989. The influence of vanadium on microorganisms and their role in the transformation of this element, in *Proc. 6th Int. Trace Element Symp.*, Vol. I, M. Anke, Ed., Molybdenum. Vanadium, Jena, Germany, pp. 74–78.
- Mishra, D. and M. Kar. 1974. Nickel in plant growth and metabolism. *Bot. Rev.* 40:395–449.
- Miyaki, Y. and E. Takaheshi. 1986. Effect of silicon on the growth and fruit production of strawberry plants in a solution culture. *Soil Sci. Plant Nutr.* 32:321–326.
- Norton, B.W. and J.W. Hales. 1976. A response of sheep to cobalt supplementation in southeastern Queensland. *Proc. Austr. Soc. Anim. Prod.* 11:393–396.

- Okawa, K. 1936. Investigations on the physiological action of silicic acid for plants. I and II. J. Sci. Soil and Manure, Japan 10:95–110; 216–243.
- Okawa, K. 1937. Investigations on the physiological action of silicic acid for plants. III. J. Sci. Soil and Manure, Japan 11:23–36.
- Okuda, A., and E. Takahashi. 1962. Effect of silicon supply on the injuries of excessive amounts of Fe, Mn, Cu, AsO₃, Al, Co in barley and rice plants. J. Sci. Soil and Manure, Japan 33:1–8.
- Ozanne, P.G., E.A.N. Greenwood, and T.C. Shaw. 1963. The cobalt requirement of subterranean clover in the field. Aust. J. Agric. Res. 14:39–50.
- Playne, M.J. 1970. The sodium concentration in some tropical pasture species with reference to animal requirements. Aust. J. Exp. Agric. Anim. Husb. 10:32–35.
- Raghavendra, A.S., I.M. Rao, and V.S.R. Das. 1976. Replacibility of potassium by sodium for stomatal opening in epidermal strips of *Commelina benghalensis*. Z. Pflanzenphysiol. 80:36–42.
- Raleigh, G.J. 1939. Evidence for the essentiality of silicon for growth of the beet plant. Plant Physiol. 14:823–828.
- Schwarz, K. 1974. Recent dietary trace element research, exemplified by tin, fluorine and silicon. Fed. Proc. 33:1748–1757.
- Suehisa, R.H., O.R. Young, and D.G. Sherman. 1963. Effects of silicates on phosphorus availability to sudangrass grown on Hawaiian soils. Hawaii Agric. Expt. Stn. Tech. Bull. 51.
- Underwood, E.J. 1984. Cobalt, in *Nutrition Reviews Present Knowledge in Nutrition*, 5th ed, R.E. Olson, Ed., The Nutrition Foundation, Washington, D.C., pp. 528–537.
- Walker, C.D., R.D. Graham, J.T. Madison, E.E. Cary, and R.M. Welch. 1985. Effects of Ni deficiency and some nitrogen metabolites in cowpeas (*Vigna unguiculata* L. Walp.). Plant Physiol. 79:474–479.
- Yakumin, A.F., N. Chan Van, and I.N. Gogitov. 1991. Effect of molybdenum, vanadium and tungsten on the growth of *Anabaena variabilis* and its synthesis of nitrogenases. Microbiology (New York) 60:52–56.
- Zhu, Q. and Z. Liu. 1985. Soluble rare earth elements in soils, in *New Frontiers in Rare Earth Science and Application*, Xu, G. and J. Xiao, Eds., Proc. Int. Conf. Rare Earth Develop. App. Beijing, China. Science Press, Beijing, China, pp. 1511–1514.